Security Related Information- Withheld Under 10CFR2.390

Figure 3-8 Containment Nodes at EL. 156' – 0"

4.0 ANALYSIS RESULTS

The sequences analyzed in this section were selected to be a representative sample of Level I PRA sequences, disabling the hot leg creep rupture model as necessary to predict a higher-pressure vessel failure. All sequences in this section are run with the Cavity Flooding System (CFS) and the Emergency Containment Spray Backup System (ECSBS) available. The CFS is actuated after the onset of core damage to ensure that a significant pool of water exists in the reactor cavity at the time of vessel failure. This mitigates concrete ablation but provides a challenge in terms of containment pressurization. Actuation of the CFS during a severe accident is the expected behavior of the plant. The intent of this section is to demonstrate that for all of the sequences not predicting vessel failure below 1.72 MPa (250 psia), operator intervention of manually opening the POSRVs can indeed depressurize the primary system below 1.72 MPa (250 psia) prior to vessel failure.

4.1 R1_TLOESW003

This sequence is defined as a loss of Essential Service Water (ESW) at full power resulting in reactor scram at sequence initiation. Four Safety Injection (SI) tanks are available. AF pumps, SI pumps, Containment Spray (CS) pumps, and charging pumps are assumed to be unavailable. Due to the loss of ESW, a 21 gpm per pump seal LOCA is assumed to occur half an hour into the sequence.

Once reactor scram occurs and main feedwater is isolated, the steam generators begin to boil off their inventories. Because AF is assumed unavailable, both steam generators quickly boil dry and stop removing decay heat. Half an hour into the sequence, a 21 gpm per pump seal LOCA occurs, but the flow rate is not sufficient to depressurize the RCS. The primary system heats up and pressurizes, soon reaching the POSRV relief setpoints and causing the valves to open. Primary system inventory is steadily lost through the POSRVs and RCP seals, causing the core water level to decrease. The discharge from the POSRVs is sparged into the In-containment Refueling Water Storage Tank (IRWST), condensing the steam and preventing additional containment pressurization. The core is soon uncovered, causing the CET to reach 1,200°F, signaling the onset of core damage.

Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4), and time of operating the POSRV after entering severe accident conditions (0.00 hr, 0.50 hr, and 1.00 hr). Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-1 and Figure 4-2 while detailed sensitivity analysis is presented in Table 4-1. Depressurization is successful for this sequence if two POSRVs are opened within 0.50 hours after entering severe accident conditions, or if four POSRVs are opened within 1.00 hours after entering severe accident conditions.

TS

Figure 4-1 R1_TLOESW003 Primary Pressures

TS

Figure 4-2 R1_TLOESW003 Pressurizer Gas Temperatures

Table 4-1 R1_TLOESW003 Success Criteria Based on Operator Interventions

TS

4.2 R3 LOOP004

This sequence is defined as a Loss of Offsite Power (LOOP) at full power resulting in reactor scram at sequence initiation. Diesel Generators (DG) are assumed to be started to provide backup power. Four SI tanks are available. AF pumps, SI pumps, SC pumps, and charging pumps are assumed to be unavailable.

Once the LOOP occurs, the steam generators begin to boil off their inventories. DGs are assumed to start successfully, but no Engineering Safety Feature (ESF) systems are recovered. Because AF system is unavailable, both steam generators quickly boil dry and stop removing decay heat. The primary system heats up and pressurizes, soon reaching the POSRV relief setpoints and causing the valves to open. Primary system inventory is steadily lost through the POSRVs, causing the core water level to decrease. The discharge from the POSRVs is sparged into the IRWST, condensing the steam and preventing containment pressurization. The core is soon uncovered, causing the CET to reach 1,200°F, signaling the onset of core damage.

Hot leg creep rupture is disabled for this sequence. Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4), and time of operating the POSRV after entering severe accident conditions (0.00 hr, 0.50 hr, and 1.00 hr). Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-3 and Figure 4-4, while detailed sensitivity analysis is presented in Table 4-2. Depressurization is successful for this sequence if at least two POSRVs are opened within 1.00 hours after entering severe accident conditions.

TS

Figure 4-3 R3_LOOP004 Primary Pressures

TS

Figure 4-4 R3_LOOP004 Pressurizer Gas Temperatures

Table 4-2 R3_LOOP004 Success Criteria Based on Operator Interventions

TS

4.3 R4 SBO002

This sequence is defined as a station blackout occurring at full power. Four SI tanks are available. Alternate AC (AAC) power is assumed to become available 30 minutes into the sequence. When AAC becomes available, only motor-driven AF system is recovered. SI pumps, CS pumps, and charging pumps are unavailable for the entirety of the sequence. It is assumed that no RCP seal LOCA occurs for this sequence.

At sequence initiation, all ac and dc power is lost, leading to a loss of all ESF systems. 30 minutes into the sequence, AAC power is recovered, allowing for the operation of motor-driven AF system. Motor-driven AF system is capable of removing decay heat from the primary system until Condensate Storage Tank (CST) inventory is eventually depleted. Once CST inventory is depleted, the steam generators begin to boil off their inventories. Both steam generators eventually boil dry and stop removing decay heat. The primary system heats up and pressurizes, soon reaching the POSRV relief setpoints and causing the valves to open. Primary system inventory is steadily lost through the POSRVs, causing the core water level to decrease. The discharge from the POSRVs is sparged into the IRWST, condensing the steam and preventing containment pressurization. The core is soon uncovered, causing the CET to reach 1,200°F, signaling the onset of core damage.

Hot leg creep rupture is disabled for this sequence. Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4), and time of operating the POSRV after entering severe accident conditions (0.00 hr, 0.50 hr, 1.00 hr, 1.50 hr, and 2.00 hr). Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-5 and Figure 4-6, while detailed sensitivity analysis is presented in Table 4-3. Depressurization is successful for this sequence if at least two POSRVs are opened within 2.00 hours after entering severe accident conditions.

TS

Figure 4-5 R4_SBO002 Primary Pressures

TS

Figure 4-6 R4_SBO002 Pressurizer Gas Temperatures

Table 4-3 R4_SBO002 Success Criteria Based on Operator Interventions

TS

4.4 R5 SBO005

This sequence is defined as a station blackout occurring at full power. AAC power is assumed to be unavailable. Four SI tanks are available. Backup batteries are available, allowing the operation of turbine-driven AF system for 16 hours. SI pumps, CS pumps, and charging pumps are unavailable for the entirety of the sequence. RCS depressurization using the RD function, alignment of the three-way valves to the steam generator compartment, and CFS actuation are assumed to occur one hour prior to battery depletion. It is assumed that no RCP seal LOCA occurs for this sequence.

At sequence initiation, ac power is lost, leading to a loss of all ESF systems. Due to the availability of the backup batteries, turbine-driven AF system is able to operate for the first 16 hours, supplying feedwater to both steam generators and cooling the RCS. 15 hours into the sequence, operators are assumed to align the three-way valves to the steam generator compartment in order to prevent hydrogen accumulation in the IRWST, actuate the CFS to allow for gravity-driven water flow from the IRWST into the reactor cavity, and open the POSRVs to depressurize the primary system. Depressurization of the primary system allows the available SI tanks to inject. The core initially remains covered; however, the steam generators are unable to remove decay heat from the RCS due to the low primary system pressure. The inventory in the primary system is steadily boiled off and the core is eventually uncovered, causing the CET to reach 1,200°F and signaling the onset of core damage. The core begins to melt and relocate to the Reactor Pressure Vessel (RPV) lower plenum. This produces a brief pressure spike in the RCS due to the rapid steaming of the water pool that exists in the lower plenum.

Hot leg creep rupture is disabled for this sequence. Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4). Sequence time of 15 hours, or one hour before battery is depleted, is reached before severe accident criteria are met; therefore, only the number of POSRVs to be manually opened is varied for this sequence. Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-7 and Figure 4-8, while detailed sensitivity analysis is presented in Table 4-4. Depressurization is successful for this sequence if at least two POSRVs are opened.

TS

Figure 4-7 R5_SBO005 Primary Pressures

TS

Figure 4-8 R5_SBO005 Pressurizer Gas Temperatures

TS

Table 4-4 R5_SBO005 Success Criteria Based on Operator Interventions

4.5 R9 SBO006

This sequence is defined as a station blackout occurring at full power. AAC power is assumed to be unavailable. Four SI tanks are available. Backup batteries are available, allowing the operation of turbine-driven AF system for 2 hours. SI pumps, CS pumps, and charging pumps are unavailable for the entirety of the sequence. RCS depressurization using the RD function, alignment of the three-way valves to the steam generator compartment, and CFS actuation are assumed to occur one hour prior to battery depletion. It is assumed that no RCP seal LOCA occurs for this sequence.

At sequence initiation, ac power is lost, leading to a loss of all ESF systems. Turbine-driven AF system is initiated and operates until battery depletion occurs at 2 hours, supplying feedwater to both steam generators and cooling the RCS. One hour into the sequence, operators are assumed to align the three-way valves to the steam generator compartment in order to prevent hydrogen accumulation in the IRWST, actuate the CFS to allow for gravity-driven water flow from the IRWST into the reactor cavity, and open the POSRVs to depressurize the primary system. Depressurization of the primary system allows the available SI tanks to inject. The core initially remains covered; however, the steam generators are unable to remove decay heat from the RCS due to the low primary system pressure. The inventory in the primary system is steadily boiled off and the core is eventually uncovered, causing the CET to reach 1,200°F and signaling the onset of core damage. The core begins to melt and relocate to the RPV lower plenum. This produces a brief pressure spike in the RCS due to the rapid steaming of the water pool that exists in the lower plenum.

Hot leg creep rupture is disabled for this sequence. Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4). Sequence time of one hour, or one hour before battery is depleted, is reached before severe accident criteria are met; therefore, only the number of POSRVs to be manually opened is varied for this sequence. Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-9 and Figure 4-10, while detailed sensitivity analysis is presented in Table 4-5. Depressurization is successful for this sequence if at least two POSRVs are opened.

TS

Figure 4-9 R9_SBO006 Primary Pressures

TS

Figure 4-10 R9_SBO006 Pressurizer Gas Temperatures

Table 4-5 R9_SBO006 Success Criteria Based on Operator Interventions

TS

4.6 R10 SGTR10

This sequence is defined as a steam generator tube rupture occurring at full power. The break is a double ended rupture of one generator tube nine meters above the tube sheet of a single steam generator. Four SI tanks and motor-driven AF system are available. SI pumps, CS pumps, and charging pumps are assumed to be unavailable. Three hours into the sequence, operators are assumed to initiate cooldown and depressurization of the RCS at a rate of 100°F per hour by the manual actuation of two steam generator Pilot Operated Relief Valves (PORV) in the intact steam generator.

Due to the tube rupture, primary system pressure drops as RCS water flows into the ruptured steam generator. Reactor scram occurs and motor-driven AF system is initiated, pumping to both team generators. Motor-driven AF system is capable of maintaining level in the steam generators and keeping the core cooled. Three hours into the sequence, operators initiate cooldown and depressurization of the RCS using two steam generator PORVs in the intact steam generator. Due to the cooldown, the primary system depressurizes, allowing SI tanks to begin injecting. Injection of the SI tanks maintains primary system pressure. This configuration is capable of cooling the core until CST inventory eventually runs out. Once CST inventory is depleted, the core begins to boil. Steam generator and core levels are boiled down, leading to core uncovery. Once the core is uncovered, it begins to heat up. CET soon reaches 1,200°F, signaling the onset of core damage.

Several sensitivities are executed, varying the number of POSRVs manually opened (0, 2, or 4), and time of operating the POSRV after entering severe accident conditions (0.00 hr, 0.50 hr, 1.00 hr, 1.50 hr, and 2.00 hr). Plots of primary pressure and pressurizer gas temperature are shown in Figure 4-11 and Figure 4-12, while detailed sensitivity analysis is presented in Table 4-6. Depressurization is successful for this sequence if at least two POSRVs are opened within 2.00 hours after entering severe accident conditions.

TS

Figure 4-11 R10_SGTR10 Primary Pressures

TS

Figure 4-12 R10_SGTR10 Pressurizer Gas Temperatures

Table 4-6 R10_SGTR10 Success Criteria Based on Operator Interventions

TS

5.0 CONCLUSION

The goal for resolving the HPME/DCH issue is to demonstrate that HPME/DCH carries insignificant risk of uncontrolled fission product release during postulated severe accident scenarios. This is accomplished by evaluating the likelihood of containment failure as a consequence of DCH. It includes investigation of the possibility of RCS depressurization for prevention of HPME/DCH. Using the guidance contained in the SECY 93-087, APR1400 can be depressurized by opening the POSRVs, thus minimizing the potential for HPME/DCH. In this report, the RD analysis was performed for APR1400.

The RD function is diverse roles during DBAs, BDBAs, and even severe accidents. Depressurization for a severe accident using the POSRVs enables operation of the low pressure systems, such as the SC System, thus enabling additional means of core cooling. The RCS is maintained at a low pressure for cases involving a loss of core heat removal functions. This prevents the occurrence of HPME phenomenon, and prolongs the reactor vessel integrity.

In this report, the main focus is on the following three conditions that are required for a successful de-pressurization: (i) RD function is performed after the CET exceeds 922K (1,200°F); (ii) the POSRVs can only be guaranteed to open when the temperature is lower than 644K (700°F); and, (iii) the RCS should be depressurized below 1.72 MPa (250 psia) before the RV fails. The depressurization evaluation was considered successful if these three conditions were met.

As shown in Section 4 of this report, HPME can be prevented for the 10 analyzed sequences. For certain sequences (R2_MLOCA003, R6_SLOCA008, R7_PR-A-SL007, R8_MLOCA002), vessel failure occurs at a sufficiently low pressure, while for other sequences, operator intervention is necessary. Operation of only two POSRVs within a half hour of the plant entering a severe accident is sufficient for all the sequences that are being considered. The results are in compliance with SECY-93-087.

6.0 REFERENCES

1. FAI/12-0005, “MAAP 4.0.8 Transmittal document,” EPRI, Palo Alto, CA, Feb 15, 2012.
2. SECY-93-087, “Policy, Technical, and Licensing issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) designs”, USNRC, April 2, 1993.
3. DOE/ID-10271, “Prevention of Early Containment Failure due to High Pressure Melt Ejection and Direct Containment Heating for Advanced Light Water Reactors”, March 1, 1990
4. N. K. Tutu, et. Al., “Low-Pressure Cutoff for Melt Dispersal from Reactor Cavities”, BNL-NUREG-41753, Brookhaven National Laboratory. Jan, 1988